All-sky GPM Microwave (GMI) Radiance Data Assimilation Global Products from GEOS System in Support of the GPM Mission



^{1,2}Min-Jeong Kim, ^{1,2}Jianjun Jin, ¹Will McCarty, ^{1,3}Amal El Akkraoui, ¹Ricardo Todling, ¹Ron Gelaro, and ^{1,3}Wei Gu

1. Global Modeling and Assimilation Office (GMAO), NASA GSFC, 2. GESTAR, 3. SSAI

Motivation and Objective of Study

• Data assimilation, which combines the information from observations and a short-range forecast, is a powerful tool to estimate the initial state of the atmosphere for NWP forecasts. Assimilating satellite observations from microwave sensors such as GPM Microwave Imager (GMI), AMSU-A, MHS, and ATMS in cloudy and precipitating regions can provide critical constraints on meteorological parameters in dynamically sensitive regions and make significant impacts on forecast accuracy for precipitation.

• To expand the existing capabilities assimilating satellite radiance data in clear-sky condition, the NASA GMAO has been pursuing efforts to utilize all-sky (clear+cloudy+precipitating) microwave radiance data in the GEOS-5 Atmospheric Data Assimilation System (ADAS). The project has made considerable progress and the framework to assimilate all-sky GMI radiance data over the ocean is currently being tested to be implemented in the GMAO's operational forecast system by the end of 2017.

• In this poster, the current status of developing all-sky microwave radiance data assimilation system in the GEOS-5 system and implementation results to utilize all-sky GMI radiance data over Ocean are presented. In addition, work progress in enhancing our all-sky system such as dynamic thinning method is introduced. These enhancements are expected to extend the scope of all-sky radiance assimilation to include more microwave measurements and, in turn, lead to improved analyses and forecasts.

Goddard Earth Observing System (GEOS) and Its Atmospheric Data Assimilation System

The GEOS-5 system (Figure 1) consists of a group of model components that can be connected in a flexible manner in order to address questions related to different aspects of Earth System. The main components are:

- Atmospheric General Circulation Model (AGCM)- Predictive model components for the atmosphere and land. Catchment Land Model includes a multi-layer global snow model.
 Ocean General Circulation Model (OGCM)-
- Ocean General Circulation Model (OGCM)Predictive model components for the ocean and sea ice, using a specified atmospheric state to force the ocean.
- Chemistry-Climate Model (CCM)- This model includes interactive chemistry component allowing feedbacks between chemical composition and the circulation.

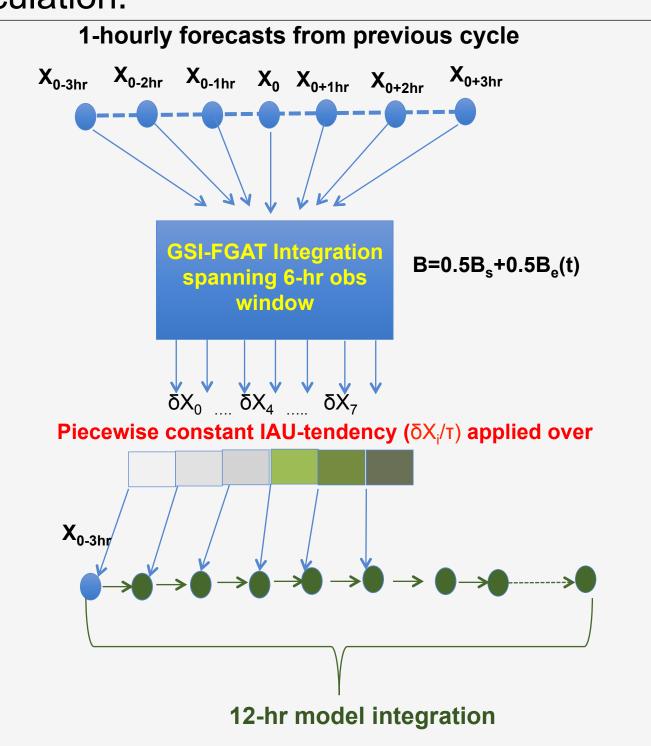


Figure 2: Description of GEOS-5 Atmospheric Data Assimilation System (ADAS) which generates atmospheric analyses by combining model background fields and observed measurements.

depending on the cloudiness.

AMSU-A, and MHS data assimilation over land.

NOAA/GFDL dynamics GMAO physics OSFC/GOCART/Aerosols IPCC aerosol and trace gas concentrations NASA Clobal Modeling Institute chemistry

Figure 1: Components considered in GEOS-5 AGCM

- Chemistry-Transport Model (CTM) Compute chemical reaction using specified meteorological conditions (winds, temperature, moisture, and clouds)
- The GEOS-5 AGCM employs a finite-volume cubed-sphere dynamical core (Putman and Lin 2007) for hydrodynamics and the physics package (Molod et al. 2012) includes moist processes, radiation, turbulent mixing and surface processes. Notably, the moisture physcis package in GEOS-5 will be enhanced with a two-moment cloud microphysics scheme (Barahona et 2014) in the next GEOS-5 AGCM system upgrade in near future. That two-moment scheme will provide estimates of cloud particle size distributions (PSD) in addition to cloud condensate amounts.
- Atmospheric Data Assimilation System (ADAS) in GEOS-5 is currently based on Hybrid 4D-EnVar analysis Solver (Figure 2). It combines information from irregularly distributed observations with the GEOS-5 AGCM model state in such a way as to minimize a specified cost function.

Assimilation Methodology

Observation Operator

Scattering parameters for non-spherical frozen precipitation are calculated using the Discrete Dipole Approximation (DDA) method of Liu (2008) and used to construct a look-up table for the CRTM in this study. For each of 11 nonspherical ice crystal shapes, a CRTM cloud coefficient lookup table was made in-house for 33 microwave frequencies between 10.65 GHz and 190.31 GHz, for seven atmospheric temperatures between 243 K and 303 K, and for 405 effective radius sizes starting from 0.005 mm. Field et al. (2007) particle size distribution is assumed for frozen hydrometeor.

Marshall-Palmer size distribution (Marshall and Palmer 1948) is assumed for liquid hydrometeors.

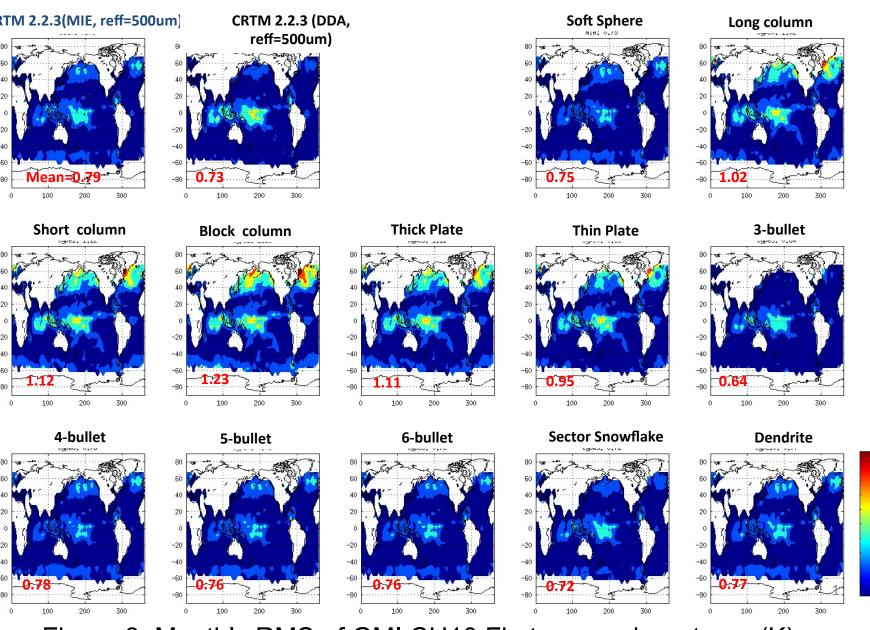


Figure 3: Monthly RMS of GMI CH10 First-guess departures (K)

Observation Error & Background Error

To consider non-Gaussian characteristics, relatively large representativeness errors, and complexities of observation operators for loud and precipitation affected radiance data, the observation errors estimated in this study are based on a symmetric observation error model, suggested in Geer and Bauer (2011).

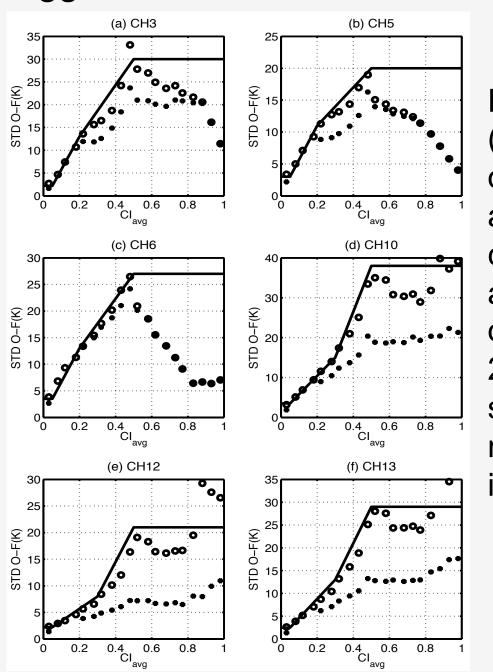


Figure 4 (left): Standard deviation (STD) of GMI first-guess departures of all observations (open circle) and assimilated observations (closed circle) binned as a function of averaged cloud index for observations between 1 December 2015 and 31 December 2015. Bin size is 0.05. The observation error model applied in this study is shown in a solid line.

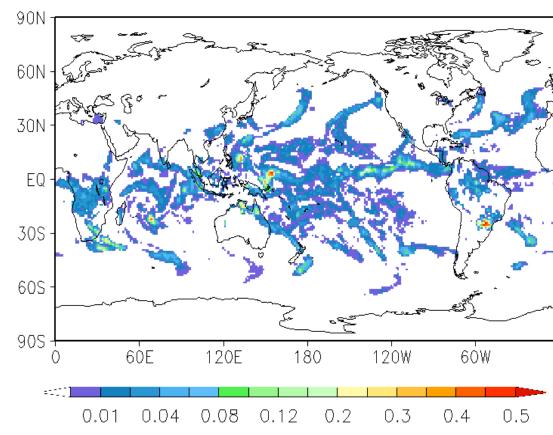


Figure 5 (right): Example of ensemble spread of cloud liquid water (g kg⁻¹) at 850 hPa calculated with 32 ensemble member forecasts from GEOS on 1200 UTC 12 December 2015.

Bias Correction

As with clear-sky radiances in the GEOS, bias correction for all-sky microwave radiances is performed using a variational bias correction (VarBC; Dee 2004, Auligne et al. 2007) scheme that estimates bias correction coefficients as part of the variational assimilation. For the all-sky implementation, two changes were made to VarBC: First, the retrieved cloud liquid water path was excluded as a predictor. Second, only near-clear sky observations with near-clear sky background profile are used in updating bias correction coefficients. Data used for bias correction coefficient updates are restricted to regions where the observed cloud index, $CI_{o,}$ is less than 0.05, the simulated cloud index, CI_{g} , is less than 0.05, and the difference between CI_{o} and CI_{o} is less than 0.005.

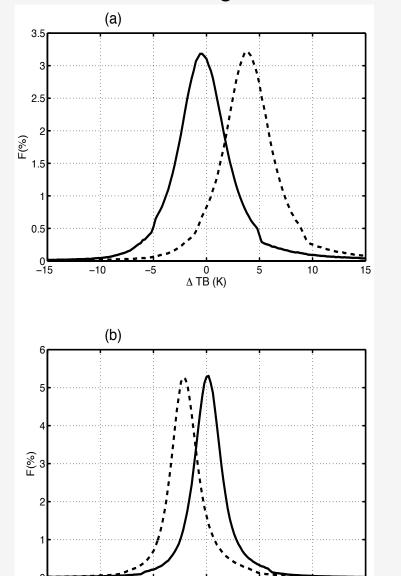
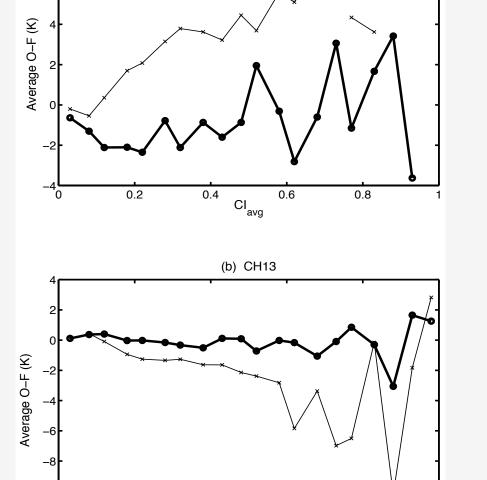


Figure 6 (left): Histograms of all-sky first-guess departures in GMI (a) channel 3 and (b) channel 13 before (dashed line) and after (solid line) bias correction is applied.

Figure 7 (right): Bias of first-guess departure as a function of Cl_{avg} for GMI channels (a) 3 and (b) 13. Thin solid (Thick solid) lines show the biases before (after) using Cl_{avg} as additional predictors in Var BC. All assimilated data points between 1 December 2015 and 31 December 2015 were used. Bin size is 0.05. Results only in the bins that have the number of data points greater than 5 are shown in this figure.



Framework to include All-sky GMI Radiance Data

	Clear-sky	All-sky
State variables	T, q, Ps, oz, Tskin, u, and v	T, q, Ps, oz, Tskin, u, v, ql, qi, qr, and qs
Analysis variables	Ψ, X _{unblanced} , T _{unblanced} , Ps _{unbalanced} ,	Ψ, X _{umblanced} , T _{umblanced} , Ps _{umbalanced} , RH, oz,
	RH, oz, and Tskin	Tskin, ql, qi, qr, and qs
Background Error	Ψ, X _{unblanced} , T _{unblanced} , Ps _{unbalanced} ,	Ψ, X _{umblanced} , T _{umblanced} , Ps _{umbalanced} , RH, oz,
	RH, oz, and Tskin	Tskin, ql, qi, qr, and qs (See Section 4.4)
Observation operator	CRTM (Version 2.2.3)	CRTM (Version 2.2.3) with a
		reconstructed cloud coefficient file of this
		study (Section 4.1)
Observation Error	Constant (and inflated during	Symmetric error model (Geer and Bauer
	quality control process)	2011) (See See Section 4.2)
Quality control	Screen out cloud affected	Keep cloud and precipitation affected
	radiance	radiance
		Screen out data over ocean if SST < 278K
Bias correction	Constant, lapse rate, square of	Constant, lapse rate, lapse rate2, cos
predictors in VarBC	lapse rate, cosine of the zenith	(zenith angle),
	angle, and cloud liquid water path	CIavg, CIavg ² (see Section 4.3)

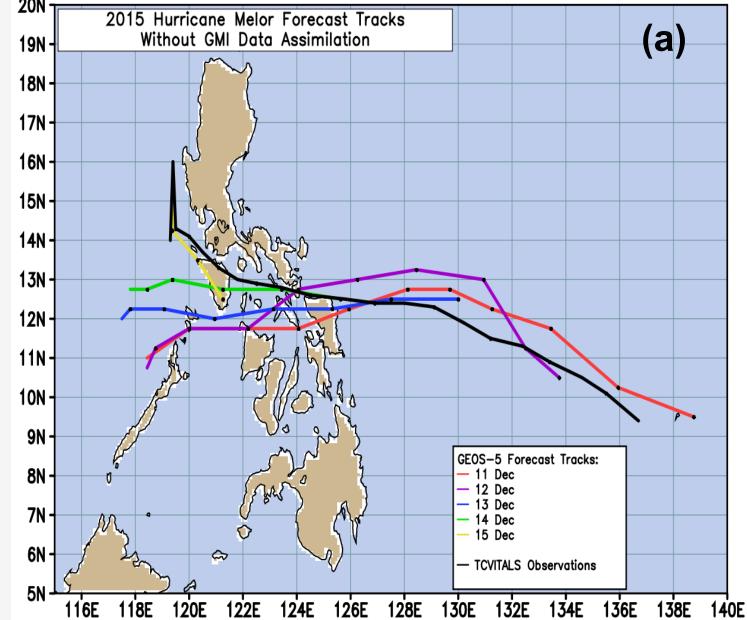
Table 1 summarizes new components added to assimilate all-sky microwave radiance data n GEOS-5 ADAS.

- T: atmospheric temperature q: specific humidity
- humidity
 Tskin: skin temperature
- Ps: surface pressure
- oz: ozone mixing ratio
 u: u-wind,v: v-wind
- ql: liquid cloud mixing ratio qi: ice cloud mixing ratio
- qr: rain water mixing ratio qs: snow water mixing ratio, Ψ: stream
- function

 X_{unblanced}:unbalanced velocity potential
- T_{unblanced}:unbalanced temperature
 Ps_{unbalanced}:unbalanced surface pressure
 RH: relative humidity.

Impacts on GEOS Hurricane Forecasts

All-sky GMI radiance data assimilation changes lower tropospheric moisture and temperature near especially tropics in the analysis and forecasts. Those impacts contributed to noticeable positive impacts of all-sky GMI assimilation on hurricane forecasts as demonstrated in figures below. Figure 8 shows that GMI radiance data assimilation positive impacts on GEOS-5 hurricane track forecasts for the Hurricane Melor, which a powerful tropical cyclone that made landfall on the Philippines at 0543 UTC 14 December 2015. The track changes were contributed from the significant changes the GEOS moisture, wind, temperature ,and surface pressure analyses by assimilating the GMI observations as illustrated in Figure 9.



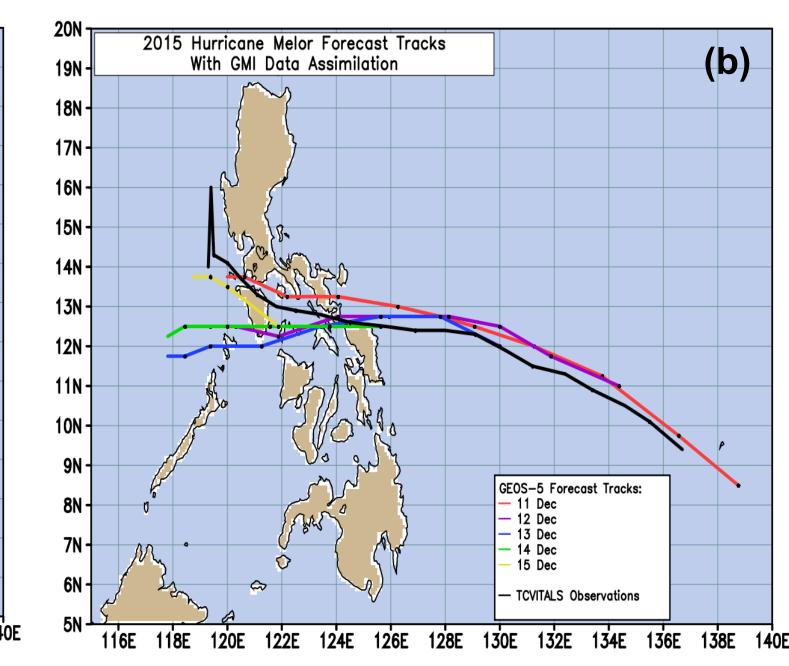
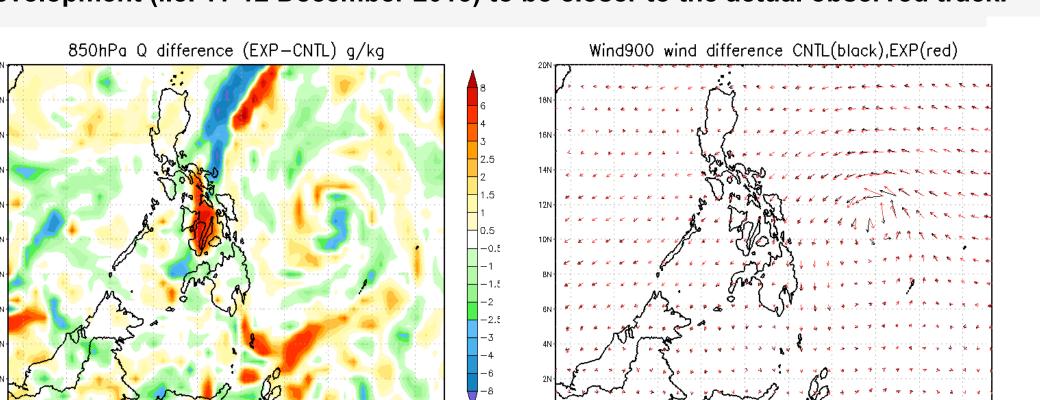


Figure 8: Comparisons of GEOS-5 forecasts without and with the assimilation of all-sky GMI data demonstrate that all-sky GMI data helped improve 5 day GEOS-5 hurricane Melor track forecasts especially at the early stage of storm development (i.e. 11-12 December 2015) to be closer to the actual observed track.



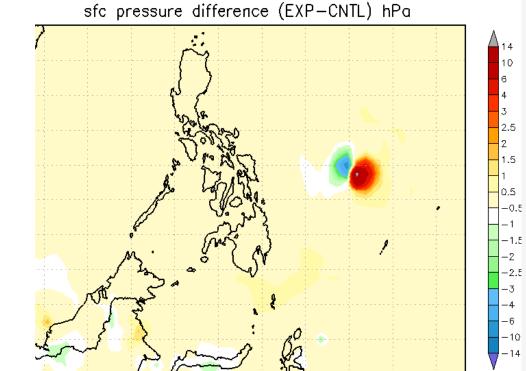
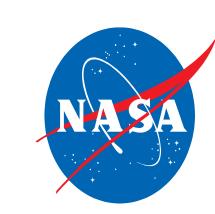


Figure 9: Differences in Analyses with and without assimilating GMI all-sky radiances in GEOS NWP experiments.

Any questions or comments? Please contact
Min-Jeong Kim
Phone:301-614-5730
E-mail: Min-Jeong.Kim@nasa.gov
Web: gmao.gsfc.nasa.gov



• Extending to all-sky AMSU-A, all-sky MHS, and all-sky ATMS data assimilation: We are currently testing all-sky data assimilation framework to assimilate AMSU-A (CH4-CH6), MHS (all-channels), and ATMS data in cloudy and precipitating regions.

Enhancements for GMI Data Assimilated GEOS Model

• Applying dynamic thinning distances: Most of other satellite radiance data assimilated in

GEOS-5 ADAS are thinned with 145 km thinning distance to avoid spatially correlated

observation errors. Test results (not shown here) demonstrated that assimilating denser data

with smaller thinning distance in storm regions resulted in improvements in storm track and

intensity forecasts. Therefore, we included a scheme to decide the thinning distance flexible

• Extending to All-sky GMI data over land, snow, and ice surfaces: Land surface emissivity

at microwave frequencies are vary in a complex way with surface types, roughness, and moisture

among other parameters. Efforts to estimate (retrieve) microwave surface emissivities using

channels not assimilated yet frequency close to the frequencies that are assimilated. A method

developed by Karbou (2007) and currently being utilized in ECMWF (Krzeminiski and Bormann 2016;

Baordo et al. 2015) for AMSU-A, MHS, SSMIS data is currently being tested in GSI to improve GMI,

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